CHAPTER 8

CHAPTER 8: SYNTHESIS

8.1 Introduction

The VS Complex consists of the proximal products of effusive felsic eruptions, namely lavas, domes, cryptodomes, and partly extrusive cryptodomes, and minor mafic intrusions. These units alternate with submarine eruption-fed felsic pyroclastic deposits and the resedimented equivalents of both the effusive and pyroclastic facies. There are distinct regional variations in the internal architecture of the VS Complex throughout the Iberian Pyrite Belt, defined by different combinations of these facies.

8.2 Depositional setting of the VS Complex

The VS Complex aggraded in a submarine basin, as indicated by abundant marine fossils such as dasycladales (Soriano and Marti, 1999; this study), echinoderms (Soriano and Marti, 1999), ammonoids (Korn, 1997) and radiolarians (Strauss, 1970; Leistel et al., 1998a; this study). The massive sulfide deposits that occur throughout the Iberian Pyrite Belt also indicate a submarine depositional environment (Herzig and Hannington, 1995; Barrie and Hannington, 1999). The presence of thick, massive mudstone intervals and massive to normally graded volcaniclastic units typical of deposits from water-supported gravity currents, and absence of tractional sedimentary structures, suggest the submarine setting was below wave base. Abundant hyaloclastite is also consistent with a subaqueous setting.

8.3 Types of volcanoes

Felsic lava-cryptodome-pumice cone volcanoes are the typical volcano type of the VS Complex of the Iberian Pyrite Belt. These volcanoes were constructed by different proportions of felsic lavas/domes and pyroclastic facies at submerged intrabasinal vents. The source vents for the pyroclastic facies were probably submarine, because the abundant lapilli-size pumice (now fiamme) recognised in the pyroclastic units suggests direct delivery of hot pumice into water, and the poorly sorted, thick and coarse nature of these units suggest they are proximal (e.g. Whitham and Sparks, 1986; McPhie and Allen, 2003; Kano et al., 1996). The absence of clasts from subaerial setting is also consistent with source vents that were submerged. Components from shallow submarine settings (dasycladales) were remobilised to deep parts of the basin and do not indicate shallow depositional settings. The milky quartz clasts that occur in some volcaniclastic units have uncertain origin, but are probably intrabasinal or from the basement, beneath intrabasinal vents. The occurrence of several lavas and pyroclastic units at the same locality indicates that the VS Complex records several effusive and explosive eruptions. Formation of the VS Complex was continuous at some locations (e.g. Albernoa, El Almendro-Villanueva de los Castillejos, Cerro de Andévalo and upper part of the Serra Branca section), and punctuated at others (e.g. Neves Corvo, lower part of the Serra Branca section and Paymogo quarry). Although dominated by the products of felsic volcanic centres, there is no positive evidence for a contribution from felsic calderas.

The lavas/domes are probably more voluminous than the felsic pyroclastic units, and vary in thickness from ~20 m to >400 m. They are mainly composed of hyaloclastite that surrounds relatively thin coherent interiors. The lavas/domes have marginal aprons of resedimented autoclastic debris that pass laterally to beds of crystal-rich sandstone and siltstone facies. The pyroclastic facies are common throughout the VS Complex and consist of fiamme, quartz and feldspar crystal fragments, and altered matrix that was probably originally glassy ash. The phyllosilicate-rich fiamme are aligned parallel to the bedding and typically lenticular. The fiamme are quartz- or quartz- and feldspar-phyric and occur together with blocky clasts that show no evidences of compaction. These characteristics suggest that the fiamme were preferentially compacted because of their high porosity, and that they were originally pumice clasts.

Most of the felsic pyroclastic units occur in thick, coarse, weakly graded beds of fiamme (pumice) breccia that were probably deposited from high-concentration water-supported gravity currents. Diffusely to well-bedded fiamme sandstone and mudstone facies are also abundant and could be the distal equivalents of the coarse pumice breccia beds. Coarse fiamme that occur isolated or scattered in mudstone may have been large, temporarily buoyant pumice clasts that eventually became waterlogged and sank at the same time as much finer sediments. This facies is also interpreted to have formed in distal setting.

Felsic cryptodomes and partially extrusive cryptodomes are less common than lavas, domes or pyroclastic facies and may have lateral aprons of resedimented autoclastic debris. The syn-volcanic felsic intrusions were identified at Serra Branca, and possibly Neves Corvo and Odiel River, and occur close to the top of the VS Complex. Mafic units are minor compared with the felsic units and the ones studied are mainly intrusions.

The internal stratigraphy of the VS Complex cannot be correlated regionally due to the wide separation and distinct evolution of each volcanic centre. However, within the relatively small study areas (up to ~60 km^2) occupied by the separate volcanoes, it is possible to reconstruct the facies architecture and stratigraphy in considerable detail.

8.4 Reassessment of syn-volcanic intrusions and peperite

Sediment-matrix igneous breccias are common in the VS Complex and occur at the top and basal contacts of the felsic coherent units. These complex breccias may have had several origins. In most cases examined for this study, they are confidently attributed to infiltration of sediment into the hyaloclastite carapace of felsic lavas or domes, rather than peperite. At Albernoa, the sedimentary component of the infiltration breccia is locally macro-spheroidal jasper. The extremely well preserved macro-spheroidal textures formed from colloidal silica that filled pore spaces in carapace breccia of the dacitic lava. Peperite was confidently identified only at the lower contacts of the felsic lavas and domes and at some top contacts of the syn-volcanic cryptodomes. Other sediment-matrix igneous breccias recognised in the VS Complex formed by mixing of monomictic volcanic components and unconsolidated background sediments derived from the seafloor, in water-supported gravity currents. The correct identification of peperite versus other kinds of sediment-matrix igneous breccias is of extreme importance, for discriminating lavas from intrusions, for determining the timing of events and for the recognition of seafloor positions (prospective for VHMS deposits).

8.5 VS Complex volcanism and massive sulfide deposits

At Neves Corvo, the massive sulfide deposits have a similar age (late Strunian) to the rhyolitic lavas, determined by biostratigraphic studies using palynomorph associations (Oliveira et al., 2004). The stockworks are typically disseminated, widespread and stratabound in the pyroclastic facies, and fracture-controlled and cone-shaped in the lavas or domes. Proximity to felsic lavas or domes, the porous and permeable substrate (fiamme-rich units) and the reducing characteristics of the depositional setting, may have been important in the formation of the massive sulfide deposits at Neves Corvo. Little is known about relationship between other massive sulfide deposits and their host volcanic facies.

At Neves Corvo, three major volcanic events have been identified. The first volcanic event occurred in the late Famennian (C. Rosa et al., 2005; Oliveira et al., 2004), generating eruption-fed, felsic pyroclastic deposits that were sourced from local submarine vents. During the late Strunian, the second volcanic event produced rhyolitic lavas, also sourced from local submarine vents. The lavas underwent intense quench fragmentation and some autobrecciation. The third volcanic event identified at Neves Corvo was probably early Visean, and produced a thin, local dacitic lava or sill. The pyroclastic facies and the lava at Neves Corvo are both rhyolitic, but compositionally distinguishable, and both can be distinguished from the dacitic unit. The volcanic succession at Neves Corvo includes a significant volume of rhyolitic lavas and domes (this study) and contrasts with the dacitic lavas of Albernoa (D. Rosa et al., 2004) and Serra Branca (D. Rosa et al., in press). The rhyolitic lavas at Neves Corvo are depleted in TiO_2 and Zr when compared with the Albernoa dacitic lavas (e.g. this study and D. Rosa et al., 2004). These compositional differences could be especially important since the massive sulfides at Neves Corvo are closely associated with the rhyolitic lavas.

8.6 Directions for future research

This study shows that the VS Complex in the study areas comprises different abundances of a relatively limited number of facies, sourced from similar types of volcanoes. However, other areas where the VS Complex is exposed should be studied, in order to accurately characterise the VS Complex throughout the Iberian Pyrite Belt, because successions of different nature may occur.

Volcanic facies analysis of the volcanic successions that host the major massive sulfide deposits (other than Neves Corvo) in the Iberian Pyrite Belt is urgent. Identifying similar features among the volcanic successions that host the massive sulfide ore deposits, and any contrast with apparently barren successions, may have exploration implications, and help to define new or more restricted areas for exploration. Further compositional data on the felsic volcanic rocks may also have exploration significance. The rhyolitic lavas at Neves Corvo have slightly different compositions from other texturally similar felsic lavas and domes at Serra Branca or Albernoa.

The integration of the volcanic facies architecture with biostratigraphic data at Neves Corvo has been extremely revealing of the interplay between volcanic, sedimentary and ore forming processes. However, there is considerable scope for extending and refining the volcanological interpretation of Neves Corvo presented in this thesis.

Dating of the felsic volcanic units and the massive sulfide deposits, by both radiometric and biostratigraphic techniques, needs to be extended regionally, in order to determine whether there are any temporal patterns in volcanism and ore formation within the Iberian Pyrite Belt.

Additional study of the sediment–matrix volcanic breccias in the sections where peperite has previously been described is warranted. A critical reassessment of the origin of these sediment–matrix igneous breccias is of considerable importance in the recognition of intrusions, and hence, in determining the order of events and the location of seafloor-positions.

The mafic igneous activity has only briefly been addressed in this work as mafic facies are minor in all the areas selected for study. Areas where the mafic units are known to be thick and extensive could significantly broaden current understanding of the styles and products of VS Complex volcanism.

The distribution of the dasycladales in the VS Complex requires a clear definition. The identification of areas that may contain *in situ* dasycladales or areas, where these fossils occur close to their *in situ* growth sites, may help to define very shallow or subaerial domains in the basin.